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ABSTRACT

This report summarizes the findings of one of fourteen panels that studied progress in space science applications and defined user needs capable of being met by space-system applications. The study was requested by the National Aeronautics and Space Administration (NASA) and was conducted by the Space Applications Board. The panels comprised user specialists drawn from federal, state, and local governments. This publication reports the panel's study of user requirements in nine areas: (1) Weather and Climate; (2) Uses of Communications; (3) Land Use Planning; (4) Agriculture, Forest, and Range; (5) Inland Water Resources; (6) Extractable Resources; (7) Environmental Quality; (8) Marine and Maritime Uses; and (9) Materials Processing in Space. Also included is an assessment of the space transportation system capabilities for user requirements and a section on conclusions and recommendations. (RH)

Practical Applications of Space Systems

Supporting Paper 12

Space Transportation

A Panel Report Prepared for the

Space Applications Board

Assembly of Engineering

National Research Council

1974 SUMMER STUDY ON PRACTICAL APPLICATIONS OF SPACE SYSTEMS

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(July 1974)

PRACTICAL APPLICATIONS OF SPACE SYSTEMS

Supporting Paper 12

SPACE TRANSPORTATION

The Report of the
PANEL ON SPACE TRANSPORTATION
to the
SPACE APPLICATIONS BOARD
of the
ASSEMBLY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

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PREFACE

In November 1973, the National Aeronautics and Space Administration (NASA) asked the National Academy of Engineering* to conduct a summer study of future applications of space systems, with particular emphasis on practical approaches, taking into consideration socioeconomic benefits. NASA asked that the study also consider how these applications would influence or be influenced by the Space Shuttle System, the principal space transportation system of the 1980's. In December 1973, the Academy agreed to perform the study and assigned the task to the Space Applications Board (SAB).

In the summers of 1967 and 1968, the National Academy of Sciences had convened a group of eminent scientists and engineers to determine what research and development was necessary to permit the exploitation of useful applications of earth-oriented satellites. The SAB concluded that since the NAS study, operational weather and communications satellites and the successful first year of use of the experimental Earth Resources Technology Satellite had demonstrated conclusively a technological capability that could form a foundation for expanding the useful applications of space-derived information and services, and that it was now necessary to obtain, from a broad cross-section of potential users, new ideas and needs that might guide the development of future space systems for practical applications.

After discussions with NASA and other interested federal agencies, it was agreed that a major aim of the "summer study" should be to involve, and to attempt to understand the needs of, resource managers and other decision-makers who had as yet only considered space systems as experimental rather than as useful elements of major day-to-day operational information and service systems. Under the general direction of the SAB, then, a representative group of users and potential users conducted an intensive two-week study to define user needs that might be met by information or services derived from earth-orbiting satellites. This work was done in July 1974 at Snowmass, Colorado.

For the study, nine user-oriented panels were formed, comprised of present or potential public and private users, including businessmen, state and local government officials, resource managers, and other decision-makers. A number

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*Effective July 1, 1974, the National Academy of Sciences and the National Academy of Engineering reorganized the National Research Council into eight assemblies and commissions. All National Academy of Engineering program units, including the SAB, became the Assembly of Engineering.

of scientists and technologists also participated, functioning essentially as expert consultants. The assignment made to the panels included reviewing progress in space applications since the NAS study of 1968* and defining user needs potentially capable of being met by space-system applications. User specialists, drawn from federal, state, and local governments and from business and industry, were impaneled in the following fields:

Panel 1: Weather and Climate
Panel 2: Uses of Communications
Panel 3: Land Use Planning
Panel 4: Agriculture, Forest, and Range
Panel 5: Inland Water Resources
Panel 6: Extractable Resources
Panel 7: Environmental Quality
Panel 8: Marine and Maritime Uses
Panel 9: Materials Processing in Space

In addition, to study the socioeconomic benefits, the influence of technology, and the interface with space transportation systems, the following panels (termed interactive panels) were convened:

Panel 10: Institutional Arrangements
Panel 11: Costs and Benefits
Panel 12: Space Transportation
Panel 13: Information Services and Information Processing
Panel 14: Technology

As a basis for their deliberations, the latter groups used needs expressed by the user panels. A substantial amount of interaction with the user panels was designed into the study plan and was found to be both desirable and necessary.

The major part of the study was accomplished by the panels. The function of the SAB was to review the work of the panels, to evaluate their findings, and to derive from their work an integrated set of major conclusions and recommendations. The Board's findings, which include certain significant recommendations from the panel reports, as well as more general ones arrived at by considering the work of the study as a whole, are contained in a report prepared by the Board.**

It should be emphasized that the study was not designed to make detailed assessments of all of the factors which should be considered in establishing priorities. In some cases, for example, options other than space systems for accomplishing the same objectives may need to be assessed; requirements for

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*National Research Council. *Useful Applications of Earth-Oriented Satellites, Report of the Central Review Committee*. National Academy of Sciences, Washington, D.C., 1969.

**Space Applications Board, National Research Council. *Practical Applications of Space Systems*. National Academy of Sciences, Washington, D.C., 1975.

institutional or organizational support may need to be appraised; multiple uses of systems may ~~need to~~ be evaluated to achieve the most efficient and economic returns. In some cases, analyses of costs and benefits will be needed. In this connection, specific cost-benefit studies were not conducted as a part of the two-week study. Recommendations for certain such analyses, however, appear in the Board's report, together with recommendations designed to provide an improved basis upon which to make cost-benefit assessments.

In sum, the study was designed to provide an opportunity for knowledgeable and experienced users, expert in their fields, to express their needs for information or services which might (or might not) be met by space systems, and to relate the present and potential capabilities of space systems to their needs. The study did not attempt to examine in detail the scientific, technical, or economic bases for the needs expressed by the users.

The SAB was impressed by the quality of the panels' work and has asked that their reports be made available as supporting documents for the Board's report. While the Board is in general accord with the panel reports, it does not necessarily endorse them in every detail.

The conclusions and recommendations of this panel report should be considered within the context of the report prepared by the Space Applications Board. The views presented in the panel report represent the general consensus of the panel. Some individual members of the panel may not agree with every conclusion or recommendation contained in the report.

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CONTENTS

DEFINITION OF U.S. SPACE TRANSPORTATION SYSTEM IN THE 1980's

The United States Space Transportation System (STS) in the 1980's will consist initially of a mix of (1) unmanned launch vehicles such as Scout, Delta, Atlas-Centaur and Titan in various versions and (2) the manned Space Shuttle System (SSS). The unmanned launch vehicles will continue to provide transportation into space on a selective basis for various users until the SSS becomes fully operational and cost competitive. Although the National Aeronautics and Space Administration (NASA) is not currently planning any further funding for the development of unmanned launch vehicles, other domestic and foreign interests are expected to continue development and to improve performance, reliability, and cost.

The transport elements of the Space Shuttle System consist of the reusable Orbiter, the Spacelab, and various upper stages (called tugs) for placing and occasionally retrieving spacecraft in geostationary or other orbits higher than the Orbiter itself can attain. In addition to various more or less advanced propulsion stages matched to individual spacecraft and mission requirements, a general-purpose Interim Upper Stage (IUS) will be provided in the early 1980's. When mission requirements are clarified in accordance with continuing studies, and operational experience is digested, a reusable Full Capability Tug (FCT) may be needed to support a wide variety of orbital operations, especially in geosynchronous orbit. Beginning in the early 1980's, Spacelab will be carried in the Orbiter payload bay to and from low earth orbits and will represent an important functional part of the SSS that facilitates research and development in space as well as operational activities. Availability of Spacelab will encourage a wide variety of science and technology experiments that use ordinary, as well as specially designed, laboratory equipment and are conducted by scientific personnel and technicians. Operational measurements and processes also will be carried out under the unique conditions provided within the orbital environment. The presence of man is expected both to broaden the capability and to reduce the costs of operations in space.

Advanced propulsion systems, including solar and/or nuclear electric rocket stages, as well as advanced chemical rockets having greatly improved space transportation capabilities, may become available in the 1980's. Teleoperators* of

*Teleoperator is an electromechanical device which allows an operator to accomplish mechanical tasks from a remote location. For example, an operator inside the STS might use a teleoperator to perform tasks outside the STS.

increasing sophistication will probably be used during the latter half of the decade as an element of the STS.

SCOPE AND PROCEDURE

The Panel on Space Transportation was established to provide guidance to the other summer study panels concerning the nature of future space transportation and to identify and assess how applications envisioned by the user panels would influence or be influenced by the space transportation system of the 1980's.

All elements of the STS are briefly described as envisioned for the 1980's. The results of the approach taken by the Panel on Space Transportation in interfacing with other panels, acquiring data, preparing data, and performing analysis of user data are summarized. A comparison of user requirements with expected STS capabilities is presented for each of the user panels. The STS capabilities are discussed in terms of availability, carrying payload to orbit, and estimated costs per launch.

It is essential that interactions among space programs, space technology, and space transportation are clearly understood.

In order to assess STS capabilities to meet user requirements, the Panel on Space Transportation prepared a questionnaire for eliciting from the user panels such information as orbital parameters, data requirements, and physical and operational characteristics of potential future spacecraft responsive to user needs.

The following questions were submitted to each user panel:

1. What are the basic needs of your application that the possible use of space may offer?

   In the early 1980's?
   In the late 1980's?
   In the 1990's?

2. What information do you need about the capabilities of the space transportation system in the 1980's?

3. Are you interested in:

   Acquiring data relayed from space?
   Performing operations in space?
   Analyzing data in space in real time?

4. What earth reference are you interested in?

Is geostationary orbit beneficial?
What other altitude preferences do you have?
What precision of earth reference do you need (i.e., accuracy of location, resolution, coverage)?

5. What is your time reference requirement?

Do you need data hourly, daily, weekly, etc.?
Can you acquire your data in 7 days on-orbit, 30 days on-orbit, more than 30 days on-orbit?
If 7 to 30 days is acceptable, how frequently would you require a space flight?

6. Do you have a requirement to change orbital positions during a single mission?

7. Are you aware of any spacecraft that will satisfy your requirements?

What are the weight and size characteristics of candidate spacecraft?
If there are no available spacecraft, what are weight and size characteristics of concepts?

8. How much time is required for prelaunch installation and checkout?

Will you require a second launch if the first launch attempt fails?
What do you consider a minimum reaction time for such a second launch?

9. Is it beneficial to use man in space to reduce the design complexity of your spacecraft or sensor?

Maintenance or repair?
Operational features, e.g., reduced automation?
Have you discussed man-in-space capability with the Skylab astronauts?

10. On your equipment, what do you consider to be the most critical components? Have you considered the possibility of making provisions to replace these components on-orbit?

11. Can you identify unique requirements to provide electrical power, cooling and heating, communications, guidance and control from the launch vehicle or on-orbit carrier? Do you have unique environmental control requirements during prelaunch, ascent, or on-orbit?

12. Spacelab provides a pressurized (manned) and/or unpressurized (space-exposure) facility. Does either of these substitute for presently conceived automated satellite applications?

13. Do you foresee a role for man in tending a pallet-mounted experiment, remembering that some degree of remote control is provided from the orbiter cabin or the Spacelab pressurized module?

14. How would you use the shuttle to reduce ground test requirements? For qualification of hardware in space?

Each Panel member had a responsibility to interpret the needs of the user panels as compiled from their answers to the questionnaire. The Panel on Space Transportation also coordinated its findings with those of the Panel on Technology. The space transportation needs have been summarized for each of the nine user panels and an assessment made of the capabilities to meet these requirements within the whole U.S. Space Transportation System.

After reviewing the inputs from user panels, the Panel on Space Transportation discussed these and produced conclusions and recommendations regarding the U.S. Space Transportation System. These conclusions and recommendations are in the following categories: (1) payload and mission capabilities, (2) planned launch schedules, (3) definition of user payloads, and (4) optimization of operations. The Panel's conclusions and recommendations are presented later in this report.

ASSESSMENT OF USER REQUIREMENTS WITH USER PANELS

After receiving the completed questionnaires, the Panel on Space Transportation met with all nine of the user panels to gain a better understanding of user requirements* and to provide pertinent data as to the capabilities of the U.S. Space Transportation System. Analysis of the user requirements leads to an estimate or a definition of spacecraft and mission characteristics needed to satisfy these requirements. When these characteristics are defined, their impact on the STS is assessed.

The Panel is mindful of the distinction between weight and mass. However, since the term weight is more familiar to non-aerospace users and since to them weight is what must be lifted from the surface of the earth by a transportation system, the term weight is used in the remainder of this report in contexts in which the aerospace community might prefer the term mass.

WEATHER AND CLIMATE

The objective of the Panel on Weather and Climate was to determine ways in which space systems can be applied to obtain data for forecasting weather and climate changes. The function was divided into the following three phases according to the range desired:

- Short range local forecasting with emphasis on the monitoring of severe storms and squall lines. These forecasts usually cover periods of 24 hours and may extend from 2 to 5 days. Storms probably should be monitored continuously for periods of from one-half to several hours.

- Synoptic forecasting which extends to about 1 week. This function now is in existence and is organized under the worldwide leadership of the Global Atmospheric Research Program.

*Further details are provided in the reports of the nine user panels referred to in this paper.

Long range prediction of changes in climate.

Spacecraft characteristics required for the three phases of weather forecasting differ. For example,

> There are conceptual plans for an initial spacecraft, the Severe Storm Observing Satellite (SSOS) to be used in short range forecasting. It has a weight of 250 kg (550 lb), and dimensions of 3.1 by 1.9 m (10.3 by 6.3 ft). A later spacecraft with improved capability will be the Synchronous Earth Observatory Satellite (SEOS). It will have a weight of 2300 kg (5000 lb) and dimensions of 3.7 by 2.4 m (12 by 8 ft).
>
> For synoptic forecasting, the spacecraft is identified as the Television Infrared Observational Satellite (TIROS) which has a weight of 635 kg (1400 lb) and dimensions of 3.7 by 2.4 m (12 by 8 ft).
>
> For long range climate predictions, data on the spacecraft physical characteristics are not available at this time. It is anticipated that sensor stability will be required so that small changes can be detected during long time intervals, that is, years. Such sensors may be incorporated in the types of spacecraft used for short range and synoptic weather forecasting.

Mission requirements differ for the three phases of forecasting and include:

> For short range forecasting, a system based on the use of five satellites in fixed equatorial positions with each observing a field of view of 50°. Worldwide participation is planned and the U.S. and the U.S.S.R. will probably provide the transportation to orbit the satellites. At the present time, however, no arrangements have been made to decide what will be provided by each country. Initial launches of SSOS are planned in 1979 and launches of SEOS are anticipated between 1981 and 1985. A continuous service is desired with replacements at intervals between 2 and 5 years.
>
> For synoptic forecasting, two satellites are planned to be in near-polar orbit at 833 km (450 n. mi) and an inclination of 102°. A continuous service is planned with one launch per year during an estimated 2-year life for the spacecraft. Initial launches are planned in 1978.
>
> For long range climate predictions, no mission requirements are now available.

Requirements for all three phases of weather forecasting fall within the capability of the U.S. Space Transportation System. Initial launches of TIROS in 1978 and initial launches of SSOS in 1979 will put these systems in use during the transition from existing unmanned launch vehicles to the Space Shuttle System.

The use of Spacelab was indicated by the Panel on Weather and Climate for forecasting but detailed requirements were not available at the time of the study. Consideration has been given to the following three types of short Space Shuttle or sortie missions:

- Research and development of sensors and satellite components

- Special platforms for investigation of specialized non-recurring events and for periodic measurements of slowly varying parameters such as the solar constant

- Specialized experiments such as a cloud physics laboratory which would take advantage of the space environment to separate experimental parameters.

USES OF COMMUNICATIONS

Functions to which communications satellites contribute have been identified and are shown in Table I. The type of orbit needed and also the required satellite physical characteristics, including weight, diameter, and length, are included for each function. All satellite systems are intended to provide continuous service and each is estimated to require replacement as indicated by the given number of launches per year. Projected initial launch dates are also shown. The sequence in Table I represents an evaluation by the Panel on Uses of Communications concerning the relative importance of the functions with the most important first. The objectives of each function are as follows:

- For mobile communications and position determination, to use data from satellites and from low-cost mobile ground equipment to locate specific positions on the surface of the earth.

- For electronic message handling, to set up a system to provide point-to-point transmission of messages through satellites and ground stations. This system is anticipated as a supplement to the present mail system. It is intended to provide capability for handling a greater volume and to move letter mail more rapidly and at lower cost.

- For education, to provide high quality audio and video educational material to broad audiences through the use of satellites and low-cost ground receivers.

- For health care, to provide medical information in both audio and video formats through satellites and low-cost ground receivers.

Function	Type of Orbit	Physical Characteristics: Weight (in kilograms)	Physical Characteristics: Dimensions (in meters)	Launches: Number Per Year	Launches: Timing of First Launch
Mobile Communications and Position Determination	Synchronous	500	2 x 4	2	1980
Electronic Mail	Synchronous	2500	4 x 7	1	1980-85
Education					1980
Health Care					1980
Teleculture for Rural Areas	Synchronous	2500	4 x 7	1	1980-85
Search and Rescue	Synchronous	500	2 x 4	0.5	1980
Direct Broadcasting	Synchronous	1300	3 x 7		1980
Time and Frequency Standards	Synchronous or Near Polar	500	2 x 7	0.5	1980-85
Wildlife Tracking	Low Polar	100	0.75 x 1.5	0.5	1980-85
Amateur Activity	Synchronous	500	2 x 4	0.25	1980-85

TABLE I FUNCTIONS USING COMMUNICATIONS SATELLITES

For teleculture, to provide quality entertainment by means of high-fidelity audio and video equipment to rural areas with presentation at local theaters or available public centers.

For search and rescue, to provide sufficiently accurate position information to aid in search and rescue of lost persons, ships or airplanes and to find and rescue persons during other emergency conditions.

For disaster warning, to provide warning of disaster to urban populations through the use of aural and visual alarms located in homes.

For time and frequency standards, to supplement or replace the present time and frequency standards supplied by terrestrial high frequency radio and thus to improve the accuracy and quality of these standards.

For wildlife tracking, to provide, through satellites and small transmitters implanted on wildlife, a capability to monitor and track their locations and movements.

For amateur activity, to encourage amateur radio operators to continue to develop innovative ideas in the field of communication. The intent is to supplement existing amateur activity in low earth orbit with a transponder in a synchronous orbit.

For environmental and resources data, to provide a point-to-point capability to receive and transmit data on the surface of the earth. The data may be coded to preserve privacy for commercial users.

A number of the functions require synchronous orbits. Several of the satellites will require large diameter antennas which must be transported in a folded configuration to fit STS dimensional constraints. Retrieval of such a satellite and its antenna will require that the antenna be returned from its deployed to its folded configuration. Weight characteristics of larger satellites fit within STS capability but will possibly be too large to allow retrieval, even with the Full Capability Tug. For synchronous satellites requiring the Tug, the present payload-compartment lengths may necessitate ingenious designs of mechanisms for folding and deploying. Use of Spacelab for satellite hardware research and development is anticipated but no specific requirements are available at this time.

LAND USE PLANNING

The Panel on Land Use Planning stated that data from an Earth Resources Technology Satellite (ERTS-1, since renamed LANDSAT-1) have potential applications in mapping and in detecting changes in land use. Multispectral scanners and other sensors currently in use, however, are of limited capability.

Improvements in sensors, data processing, and data handling were seen as leading in the early 1980's to an operational spacecraft with an assured continuity of service for applications in land use planning.

Although no specific flight dates can be identified at the present time, the Panel on Land Use Planning strongly supports future use of the Space Shuttle System to launch or replace satellites, to conduct sensor and technique research and development, to calibrate and repair existing satellites, and to fill critical data gaps.

AGRICULTURE, FOREST, AND RANGE

The Panel on Agriculture, Forest, and Range defined application categories for crop survey, land use, water resources, range management, and forestry. The spacecraft characteristics required for specific applications have not yet been defined; however, requirements established by the Panel in regard to resolution, frequency of coverage, and resulting spacecraft weight and volume fall well within the capabilities of the Space Shuttle System. Best estimates by the Panel on on Space Transportation are a maximum of 1800 kg (4000 lb), a diameter of 3 m (10 ft), a length of 3 m (10 ft). Attitude control, stabilization and electric power requirements should not present any unique problems. The most significant mission requirements are resolution and frequency of coverage. Most of the objectives require a resolution of 30 m although a few missions require 10 m. Weekly coverage to 65° latitude is needed for most missions and thus requires near-polar orbits. Best observation time is estimated as between 10 a.m. and 2 p.m. It appears that geosynchronous orbits are not required for agricultural applications. All these requirements are within the capability of the U.S. Space Transportation System.

INLAND WATER RESOURCES

The Panel on Inland Water Resources identified objectives broadly as follows:

To measure water qualities including amount of contaminants such as zinc, chlorine, etc.

To measure water quantities including soil moisture, ice densities, snow densities, etc.

To make long duration measurements of seasonal changes

To measure the effects of sudden and unusual occurrences such as floods and tornados.

Implied spacecraft characteristics include a gross weight of approximately 1800 kg (4000 lb), a volume compatible with the Orbiter payload bay, and a microwave sensor with antenna.

The following are the broad mission requirements identified:

Data are desired beginning not later than 1980 with continuous monitoring thereafter.

Launch activity will extend through the 1980's.

Launch schedules will not be highly critical since continuous data are desired.

Both low and geosynchronous orbits are desired; a sun-synchronous polar orbit is necessary in some cases in order to eliminate shadows.

No requirement for orbit change has been identified.

Data frequency is hourly through weekly although some seasonal data are also desired.

Retrievability and refurbishment or replacement will depend on the cost of the spacecraft and on the development of new sensors.

Expected lifetime of the spacecraft will be approximately 5 years.

Microwave sensors will require high amounts of power and cooling.

The use of man will be required during the development phase and Spacelab will be very useful for that purpose; however, free-flying spacecraft most likely will be required for the operational phase.

All identified spacecraft and mission requirements are well within the capabilities of the U.S. Space Transportation System. However, special attention will need to be given to the following:

Design of antennas for microwave sensors so as to fit Orbiter volume limitations

Power and cooling capabilities for microwave sensors.

Many of the water resources needs depend on having a constant sun angle (sun-synchronous polar orbits) and will require launching from the Western Test Range (WTR).

EXTRACTABLE RESOURCES

The Panel on Extractable Resources identified the following potential space applications to assist in the location of non-renewable resources:

Definition and identification of metallogenic provinces

Detection of lineaments and structures related to gas, oil, and minerals

Detection of surface color anomalies

Location of bedrock.

It is envisioned that both Spacelab, equipped with proper instruments, and a free-flying spacecraft weighing between 1130 and 1360 kg (2500 to 3000 lb) and having dimensions of 3 m (10 ft) by 4.6 m (15 ft) will be needed. Specific mission requirements are:

To measure the relative motion of tectonic plates in the range of 1 to 10 cm per year

To locate ground exploration crews, once a day, to within ± 30 m (100 ft); to have capability in 1980's of ± 10 m (33 ft)

To communicate voice and digital data daily between exploration crews and a central location

To provide imagery in visible and in near and far infrared wavelengths with resolution between 15 m and 30 m (50 to 100 ft) and to provide imagery of selected targets to a resolution of 10 m (33 ft) with 64 gray scales

To provide such imagery of the entire globe four to six times per year at 10 a.m., 2 p.m., and 4 a.m. from sun-synchronous orbits

To provide imaging radar with resolution of 30 m (100 ft) and capable of penetrating cloud and foliage cover

To return 10 m (33 ft) resolution images of selected targets.

The U.S. Space Transportation System is expected to be capable of supporting the attainment of these needs. The following may impact the operations and design features of Orbiter and Spacelab:

Satellite recovery may be desirable in order to reduce cost; further study is ~~required~~.

If spacecraft orbits greater than approximately 800 km are selected, placement and recovery will require use of a Tug. Recovery capability is not contemplated for the Interim Upper Stage.

The Panel on Extractable Resources has expressed a desire to have a radar system and a high resolution camera as part of Spacelab. Current studies are considering both as part of a free-flying satellite.

Definition of the required radar system may result in antenna sizes and powers which would exceed planned STS capabilities.

ENVIRONMENTAL QUALITY

The Panel on Environmental Quality identified needs for the use of remote sensors in orbiting spacecraft for collecting environmental-quality data on local, regional, and global bases and for the use of spacecraft for relaying data from *in situ* monitors. Earth resources satellites are already providing data on environmental quality. Further improvements are needed, however, in the sensors -- such as those for measurement of water quality. Requirements include spatial and temporal resolution, area coverage, vertical resolution, increased sensitivity and specific data-delivery times. Of major concern are measurements of pollution in the lower troposphere and of pollution as a function of depth below the water surface. Use of Spacelab is being considered for experimental purposes such as studies of the use of microbiological processes to increase the efficiency of waste treatment.

Not much consideration has been given to date to the spacecraft or to the space transportation required for the needs of users in the area of environmental quality. Present NASA spacecraft such as ERTS and NIMBUS are considered to be adequate for research and development. The SSS could be usefully employed to calibrate remote sensors for environmental monitoring and to test new sensing concepts. Operational systems are needed to meet enforcement and regulatory requirements.

It is the opinion of the Panel on Space Transportation that the impact of the STS on the environmental quality of the stratosphere needs to be assessed and the retrieval of radioisotope sources and nuclear reactors (used to power spacecraft) needs to be considered.

MARINE AND MARITIME USES

The findings of the Panel on Marine and Maritime Uses reflect the statutory responsibilities of the National Oceanic and Atmospheric Administration (NOAA), the U.S. Coast Guard (USCG), and the U.S. Maritime Administration (MARAD) as well as the needs of oceanographers and operators of ships at sea. Requirements for space applications are grouped in three disciplinary areas: (1) communications, (2) position determination, and (3) monitoring of physical parameters of the oceans.

In the area of communications, objectives include:

- Improved and expanded dissemination of information concerning weather, waves, ice, time signals, etc.

- Better management of shipping and offshore operations

- Improved search and rescue missions.

A single optimum worldwide system for position determination is needed to replace regional systems.

Objectives for monitoring the physical parameters of the oceans include:

- Improved means of monitoring and forecasting changes in ice, currents, temperature, and shoreline erosion

- Improved and expanded monitoring of vessel operations within 370 km (200 n. mi) of the coast

- Improved and expanded monitoring of pollutants such as sewage, industrial waste, oil spillage, etc.

- Precise location of floating buoys and other offshore structures.

Spacecraft and sensors will be required to fulfill the stated purposes and objectives. The Panel on Marine and Maritime Uses did not define spacecraft needs in terms of weight, diameter, and length. The Panel was strongly supportive of SEASAT which has a weight of 1000 kg (2200 lb) with a diameter of 4.6 m (15 ft) and a length of 4 m (13 ft). Some space applications that potentially are the most demanding and some spacecraft characteristics that may be required are as follows:

- To locate sea ice and lake ice and to characterize the ice as new or old and soft or hard on such a time scale that vessels can use the information to navigate around or through the ice.

- A worldwide position-determination system accurate to 200 m (0.1 n. mi) so that a ship need carry only one type of navigation equipment. Coverage of the polar regions will be needed in the 1980's. The Global Positioning System (NAVSTAR), now under development by the Department of Defense, might fulfill this need.

- A position-determination system which can be used by owners of small fishing vessels. The receiver on the vessel must be inexpensive and the spacecraft must contain the necessary sophisticated equipment.

- Real-time surveillance data so the USCG can enforce international fishing agreements and apprehend vessels which discharge oil, either deliberately or accidentally.

The following mission requirements have been inferred:

Operationally, the spacecraft generally will be free-flying.

Low polar orbits are required for the communication and navigation satellites which service the polar regions and the Great Lakes.

Geostationary and low-inclination orbits are also required.

Some of the monitoring missions require orbits in the altitude range from 1000 to 1600 km (540 to 860 n. mi).

Time reference requirements may include coverage that is continuous, hourly, seasonal, annual or corresponds to the period of tidal fluctuations.

Other factors possibly impacting the STS may result from the following:

Use of aircraft for sensor development and use of Spacelab for operational test and evaluation are foreseen.

Man will be useful in Spacelab for the operational testing and evaluation of new payloads.

Communication and position-determination spacecraft should be gradually phased in during the early 1980's.

Monitoring satellites should be made available as soon as possible since NOAA, MARAD, and the USCG have statutory responsibilities which are currently difficult to meet. It is possible that because of the early need, only unmanned launch vehicles can provide the transportation for these satellites.

Because of the need for polar orbits the Western Test Range is required for launch of many missions.

MATERIALS PROCESSING IN SPACE

The Panel on Materials Processing in Space defined areas where the space environment might be utilized in the development of processes, materials, and products that will be of future benefit. The major areas of interest expressed by this Panel were in biological and metallurgical processes. The use of off-the-shelf research equipment was emphasized as a means for reducing the cost of specialized hardware to be utilized in space.

Applications proposed by the Panel are feasible using Spacelab. Advantage would be taken of the modular construction of Spacelab to allow materials and processing missions to be shared with other users. In order to have more flexibility in missions, an experimental automated processing laboratory is proposed.

This laboratory would resemble a Spacelab module. It is estimated to be 4.3 m (14 ft) in diameter, 2.1 m (6.8 ft) in length, and to have a maximum weight of 1800 kg (400 lb). This module could interface with Orbiter and be operated from Orbiter via the payload-specialist station. The module should be planned to be held in a status of near-flight readiness and could be used when an Orbiter flight can accommodate it and thus gain a higher flight load factor.

No specific orbits nor altitudes are required. The prime mission requirement is to achieve 10^{-3} gravity or less. Knowledge of magnetic fields and radiation belts in the proximity of the operational orbit is required. Orbital stay of 7 days is satisfactory for most defined missions. No materials processing requirements having a duration of more than 30 days were defined for Spacelab operations. It is assumed that the module for materials and processing will occupy one-fourth of Spacelab capability per flight. There is a desire for payload space equivalent to two missions per year but these could be spread out in fractional payloads on many missions. This approach will provide an opportunity for four flights per year, a number which should be adequate for needed research and development in materials processing during the early 1980's. No requirements for communications and data are identified beyond the planned capability of Orbiter and Spacelab. Sample return is the prime objective and only a minimum amount of telemetered data are required. The requirements for voice communications, computer capability, and data recording are seen as well within planned capability. Operation of a vacuum furnace in Spacelab will require electrical power levels and associated heat rejection capabilities beyond Spacelab and Orbiter baselines. However, these modules can be designed to provide for themselves the extra power and heat rejection. Such provisions must be accounted for as payload weight and volume. For biological missions specimen temperatures must be maintained in a range from 4°C to 16°C (40°F to 60°F) from the time of installation in the Spacelab through prelaunch, ascent, and post-landing. This requirement implies a need for ground power during prelaunch and post-landing. These periods are not in the present ground-operation schedule of the Space Shuttle System but the requirement can possibly be met by operational procedures, that is, by installation as late as 4 hours before launch and removal within 1 hour after landing.

It should be emphasized that the applications requirements as outlined by the Panel on Materials Processing in Space are totally dependent on the availability of Spacelab. Such a capability for research and development missions in space is necessary in the early 1980's to further developments in this field.

ASSESSMENT OF THE SPACE TRANSPORTATION SYSTEM CAPABILITIES FOR USER REQUIREMENTS

A summary of user spacecraft requirements and mission requirements is given in Table II. The parameters included are as follows:

1. Weight of spacecraft, for which all estimates are within the space transportation system capabilities. Estimates given take into account estimates by both user panels and the Panel on Space Transportation and should be updated periodically as development progresses.

2. Sizes of spacecraft, which are not yet defined for all users because of the state of development of user programs. However, it is anticipated that the payload volume of the Space Shuttle System will accommodate the actual design of the volume of the spacecraft.

3. Launch sites, from which all users desire to achieve appropriate orbits in order to acquire data. Of significant interest to the space transportation system is the fact that eight of the nine user panels in the 1974 Summer Study expressed a strong desire to obtain data from sun-synchronous polar orbits. Not indicated in Table II but expressed in interviews with individual user panels was an almost unanimous desire to begin obtaining data by 1980. Most user panels were unable to forecast explicitly the number of launches needed during 1980-82. However, a preponderance of needs for early acquisition of data from sun-synchronous polar orbits requires a re-examination of the initial operational date for Shuttle operations at the Western Test Range (WTR). The present plan is to begin Shuttle operations at WTR in late 1982. This time schedule clearly is not compatible with user needs. The Panel on Space Transportation points out that in order to meet user needs, either the schedule for activating the Shuttle capability at WTR must be accelerated or the use of existing unmanned launch vehicles from WTR must be extended.

4. Geosynchronous orbits, from which six of the nine user panels indicate a need to obtain some data. This requirement creates a need for some type of Tug which can transfer the spacecraft from a low earth orbit to a geosynchronous orbit.

5. Spacelab, for which the user panels express a need. Eight user panels indicate that use of Spacelab during the sensor research and development phase and for qualifying spacecraft hardware will be of real benefit. Seven user communities will then turn to free-flying spacecraft during operational phases.

Panel	Spacecraft		Low Orbit Launch Site		Geosynchronous Orbit	Spacelab	Tug	Utilize Man	Retrievable Mode	
	Weight (in kg)	Size (in meters)	ETR [a]	WTR					R&D	Operational
Weather & Climate	2270	4.5 x 4	X	X	X	R&D	X	X	X	TBD [b]
Uses of Communications	2000	10 x 4	X	X	X	R&D	X	X	X	TBD
Land Use Planning	1800 [c]	TBD	X	X	X	R&D	X	X	X	TBD
Agriculture, Forest & Range	1800 [c]	TBD	X	X		R&D	TBD	X	X	TBD
Inland Water Resources	1800	TBD	X	X	X	R&D	X	X	X	TBD
Extractable Resources	1130 [c]	4.5 x 3		X		Operational	TBD	X	X	TBD
Environmental Quality	1800 [c]	TBD	X	X	X	R&D	X	X	X	TBD
Marine & Maritime Uses	TBD	TBD	X	X	X	R&D	X	X	X	TBD
Materials Processing in Space	d	d	X			R&D		X	X	
						Operational		X		X

a Eastern Test Range; Western Test Range
b To Be Determined
c Estimated by Panel on Space Transportation
d Module to occupy one-fourth of Spacelab volume during flight

X Requirement exists

TABLE II SPACECRAFT AND MISSION REQUIREMENTS

Two panels (Panels on Extractable Resources and on Materials Processing in Space) indicate a need for use of Spacelab during operational phases also.

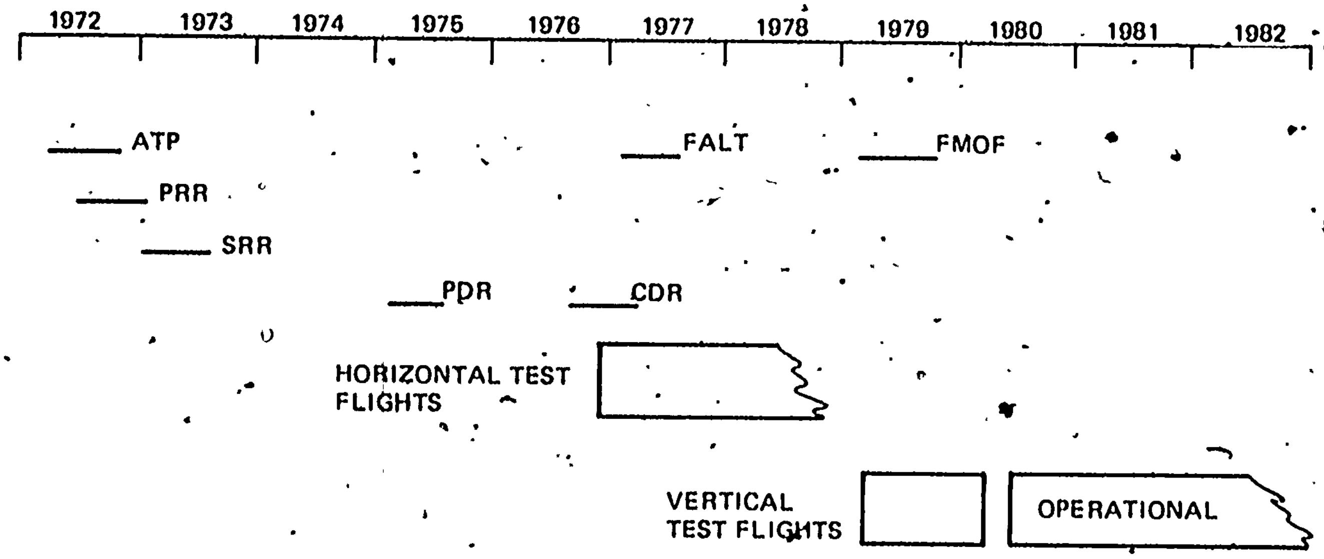
6. Tug, the use of which has been noted previously in connection with geosynchronous orbits. User panels have a need for an unmanned transfer vehicle. As requirements are better defined, the need for a manned Tug and/or a reusable Tug must be assessed.

7. Man's participation, which all users desire during the research and development phase. An ability to observe and communicate will greatly enhance the development of hardware. Man also will be of great value for assessing disasters such as floods.

8. Retrievable mode, since all users foresee advantages in retrieving spacecraft and payloads, especially during the research and development phase. Retrieval will be an invaluable tool for studying and redesigning spacecraft for the operational phase. Eight of the nine panels have expressed a desire to assess retrievability in the operational phase after system developments advance. The desirability of retrieval will depend on the cost of spacecraft and the need for development of sensors.

Transportation of payloads for space applications will be provided by existing unmanned launch vehicles through the remainder of the 1970's. A transitional period will follow as the Space Shuttle System becomes available in the 1980's and provides a greater transportation capability. The Space Shuttle System master planning schedule is shown in Figure I. The research and development phase will be completed by 1980, the transitional phase will last for several years, and a fully operational status will be reached by the early 1980's. During the transitional phase, it is anticipated that transportation of payloads will be combined with flight testing of the SSS. Full operational capability will come at the completion of flight testing when removal of test instrumentation makes the full transportation capability available for payloads. For polar-orbit capability to be attained, the WTR launch facility will need to be activated. Present planning provides for this capability to be available by the end of 1982. For applications payloads requiring polar orbit, therefore, the transitional phase from use of existing unmanned launch vehicles to operational flights on the SSS will be somewhat longer.

A summary of capability for both the existing unmanned launch vehicles and the SSS is given in Table III for geosynchronous orbits and low earth orbits at 28.5° inclination; Table IV summarizes capabilities for polar orbit. Tables III and IV show the extent of increased capability within the SSS and a trend toward lower cost in dollars per kg for transportation of payloads using the Space Shuttle. Data in Tables III and IV have been used to illustrate in Figures II and III the cost of a kg of payload delivered to several orbits as a function of payload up to full capability. Figure II covers Eastern Test Range launches into geosynchronous orbit and into orbits at 500 km (270 n. mi), both at 28.5° inclination; Figure III covers WTR launches into circular orbits at 556 km (300 n. mi) and 90° inclination. Cost figures shown in Tables III and IV are minimum values based on use of full capability of the launch vehicles. Figures II and III show how cost per kg increases as less than full capability is used. However, the choice of transportation for an application payload requires much more information than is available in Tables III and IV.



ATP Authority to Proceed
PRR Program Requirements Review
SRR System Requirements Review
PDR Preliminary Design Review
CDR Critical Design Review

FALT First Approach and Landing Test
FMOF First Manned Orbital Flight

FIGURE 1 MASTER PLANNING SCHEDULE FOR SPACE SHUTTLE SYSTEM

Also the launch vehicles shown in Table III are only a partial list of available systems. A complete list of existing systems with full descriptions of capability may be found in a handbook available from NASA.*

A plan remains to be developed for adequate space transportation during the transitional period. As applications payloads move to the more attractively priced and more versatile Space Shuttle System, existing unmanned launch vehicles are to be phased out. Proper timing will influence costs and these costs may be reduced by the development and maintenance of satisfactory transitional systems.

The Space Shuttle System will provide basic transportation to low earth orbits. Its capabilities as now planned are described in a NASA report.** They include larger payload sizes and weights at lower costs than those of expendable vehicles; man in orbit for checkout, repair, maintenance, and other functions unique to man; and the ability to retrieve payloads and return them to earth. It is anticipated that these factors may have a significant influence on the costs of applications payloads in orbits attainable by the Space Shuttle System.

Spacelab consists of a module in which equipment can be mounted in a pressurized environment and/or an unpressurized pallet on which equipment will be exposed to vacuum in space. Services provided by the pressurized module include furnishing electrical power, temperature control, computational capability, data transmission, manned attendance, and others similar to those found in a small terrestrial laboratory. The open pallet will provide power, thermal dissipation, computational capability, and data transmission. Mission durations of 7 days can be extended to about 28 days by reducing equipment weight to permit the addition of life-support systems and expendable materials for the generation of electrical power. A full description of the Spacelab capability may be found in a handbook used by the European Space Research Organization (now the European Space Agency).+ It is anticipated that equipment operating from Spacelab will require little more sophistication in design and development than equipment which is used in laboratories on earth. The cost of an application payload thus can be much lower when the application procedure is consistent with and can be a part of a Spacelab mission.

A Tug is required as an additional stage with the Space Shuttle System to place applications payloads in orbits higher than 1111 km (600 n. mi). A complete description of Tug capabilities may be found in a summary prepared by NASA.++ Payloads using a Tug do not have the advantage of manned attendance at the point when they are placed in their orbit. The payload may be checked for the last time when the Tug and payload are deployed from Orbiter. Equipment failure may be remedied by manned attendance at this point or the payload may be returned to earth by the Orbiter. Thus, factors that can reduce payload costs for the Space

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*National Aeronautics and Space Administration. *Launch Vehicles Estimating Factors for Advanced Mission Planning*. NBH-7100.5B, NASA Headquarters, Washington, D.C., 1973.

**National Aeronautics and Space Administration. *Space Shuttle Payload Accommodation*. NBH-07700, Vol. 14, Revision C, Johnson Space Center, 1974.

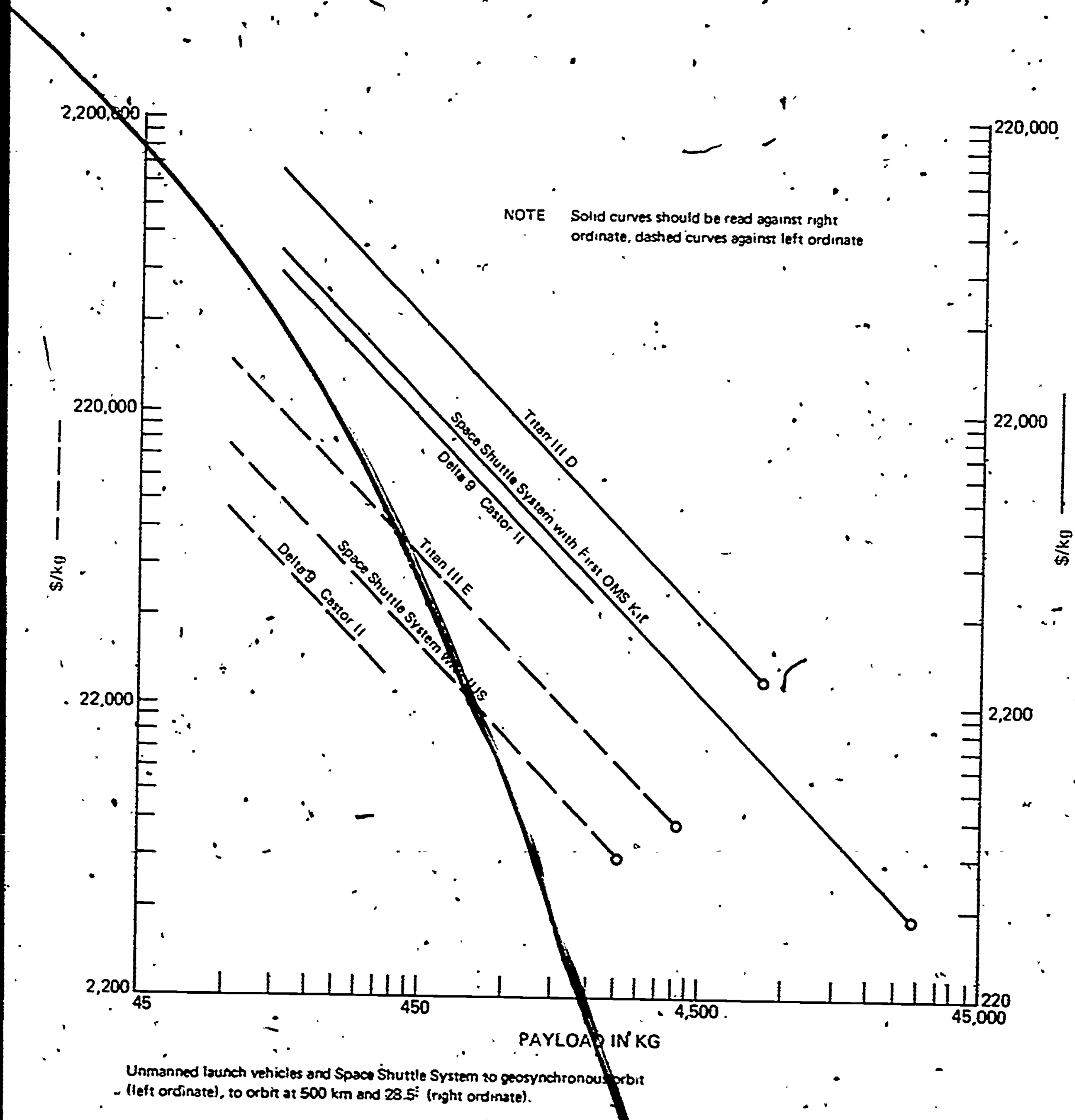
+*Spacelab Payload Accommodation Handbook*. ERNO VFW/Fokker, 1974.

++National Aeronautics and Space Administration. *Baseline Tug Summary*. Marshall Space Flight Center, 1974.

System	Payload Capability			Cost, dollars/kg	
	Weight, in kg				
	Low Orbit [a]	Geosynchronous Orbit	Diameter (in meters)	Low Orbit	Geosynchronous Orbit
Scout	154		0.9	28660	
Delta 9 Castor II	1814	329	2.4	5071	28660
Delta 9 Castor IV	2676	483	2.4		
Atlas-Centaur	4990 [b]	953	3.0	4630	24251
Titan III D	7257		3.0	2756	
Titan III C	12247	1315	3.0	2033	18960
Titan III E (Centaur)	14969	3629	3.0	2099	8598
Shuttle					
Maximum Capability	29484		4.6	357	
Integrated Orbital Maneuvering System	9072		4.6	1157	
First Orbital Maneuvering System	25855		4.6	414	
Interim Upper Stage Tug		2286	4.6		6834
Full Capability Tug		3629	4.6		3175

[a] Orbit at 500 km and inclination of 28.5°.
[b] Figure given is a theoretical capability; the present structural limit is 3175 kg.

TABLE III CAPABILITY OF SPACE TRANSPORTATION SYSTEM-EASTERN TEST RANGE



Unmanned launch vehicles and Space Shuttle System to geosynchronous orbit (left ordinate), to orbit at 500 km and 28.5° (right ordinate).

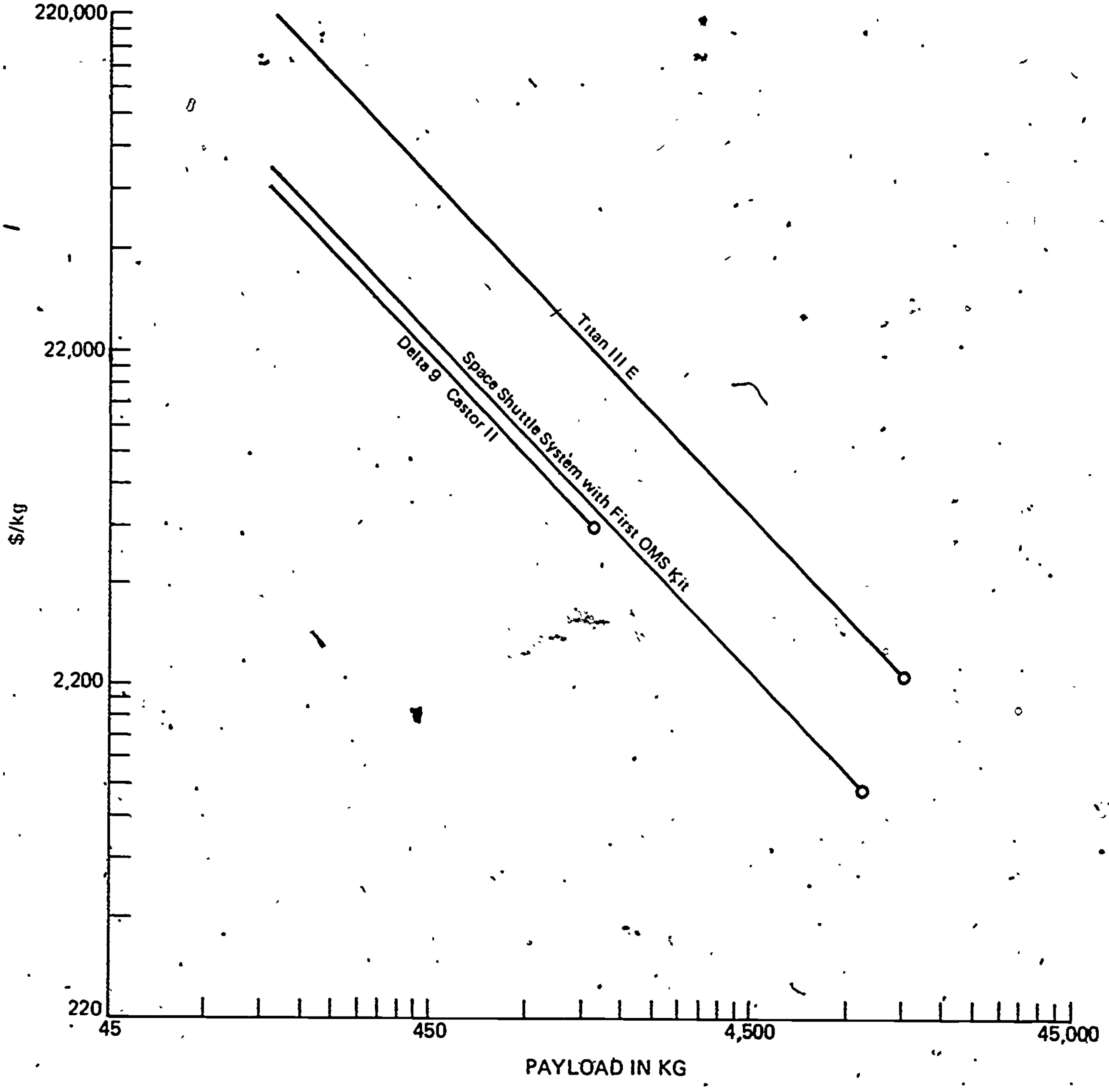
Full capability at O

FIGURE II COMPARISON OF COSTS PER KILOGRAM FOR PAYLOADS LAUNCHED AT EASTERN TEST RANGE

System	Payload Capability as Weight, in kg				Cost, in Dollars/kg	
	Polar Orbit At 90° Inclination		Polar Orbit At 104° Inclination		Polar Orbit At 90° Inclination	
	278 km	556 km	278 km	556 km	278 km	556 km
Delta 9 Castor II	1542	1361	1383	1225	5952	6834
Delta 9 Castor IV	2313	2041	2132	1905		
Atlas-Centaur [a]	4536	4264	4354	4082	5115	5445
Titan III D	8618	2722	8164	2495	2315	7341
Titan III C	10886	9979	10160	9752	2293	2491
Titan III E (Centaur)	13608	13154	13336	12701	2315	2381
Space Shuttle	16783	9525 [b]	13154	6350 [b]	626	1122

a The figures given are theoretical capability; the present structural limit is 3175 kg.
b First Orbital Maneuvering System Kit added.

TABLE IV CAPABILITY OF SPACE TRANSPORTATION SYSTEM WESTERN TEST RANGE LAUNCH



Unmanned launch vehicles and Space Shuttle System to circular orbit at 556 km and 90°.

Full capability at O

FIGURE III COMPARISON OF COSTS PER KILOGRAM FOR PAYLOADS LAUNCHED AT WESTERN TEST RANGE

Shuttle System are considerably more limited when a Tug is used. Similarly, weight and volume are more limited and less available to reduce cost.

The Interim Upper Stage now planned for use during the approximate 3-year interval between 1980 and 1983 will not provide a capability to retrieve payloads. This capability is planned for the later Full Capability Tug which, since it is not expended, might provide a reduced cost for transportation to higher orbits. The Full Capability Tug also might reduce payload costs by its capabilities for retrieval and for larger payload weight.

The present Space Shuttle System does not provide for manned capability in orbits higher than approximately 1111 km (600 n. mi). It appears that the extension of manned capability to higher orbits should be investigated since it may significantly reduce the costs of some applications payloads.

CONCLUSIONS AND RECOMMENDATIONS

PAYLOAD AND MISSION CAPABILITIES

The Panel reached the following conclusions regarding payload and mission capabilities:

> The U.S. Space Transportation System as now planned for the 1980's has ample performance capability to satisfy the needs of those users who have been able to quantify their requirements.
>
> In addition, the Panel, as a result of its interaction with user panels, is confident that those users who are currently not far enough along to specify payload details can be amply accommodated within the system capabilities as currently planned.
>
> *The Panel recommends that users who have not been able to quantify their needs for space transportation be urged to apply effort to do so.*

PLANNED LAUNCH SCHEDULES

The Panel offers the following conclusions related to the planned launch schedules:

> Potential users naturally wish to have access to space transportation as they become increasingly aware of benefits that may result from space applications.
>
> A survey of the user panels has disclosed many needs for polar orbit and this capability should be provided as early as possible within the Space Shuttle System in order to attain the projected lower cost of operation.
>
> Launch service must be assured to potential users as they proceed with internal planning, particularly if they now are or later will be dependent on current unmanned launch vehicles which are planned to be phased out.

The Panel recommends that current unmanned launch vehicles be phased out only when there is assurance of readily available and adequate Space Shuttle launch services to satisfy user needs.

DEFINITION OF USER PAYLOADS

In connection with defining user payloads, the Panel concludes that some users seek assistance in defining their payloads. Greater interaction must take place between users and knowledgeable space technologists.

In most cases, the assistance needed is:

In evaluating the feasibility of measuring from space the parameters currently measured by more conventional means

In the possible selection of alternate space-measurable parameters

In the selection or development of suitable sensors to measure these parameters.

The Panel recommends that NASA provide assistance to users for defining payloads.

OPTIMIZATION OF OPERATIONS

The Panel concludes, in relation to optimization of operations, that sophisticated integration of several primary factors is required to attain the large benefits from space applications that the U.S. Space Transportation System will make possible. One primary factor relates to spacecraft design. The two most significant elements in this area are:

Provision of one or more standardized free-flying spacecraft into which an individual user can integrate his own equipment

Availability of standardized sensor equipment capable of multimode and time-sharing operation.

A second factor that makes a special contribution to optimization is mission structuring. Here the major elements are:

Compatibility of orbit type and time for programs which are to use the payload space on a given mission

Mix of spacecraft to maximize the load factor of the payload

Selection of payload components so that handling variations in both delivery and retrieval are considered.

The Panel recommends that

In view of these interacting elements, the total responsibility for optimization of operations be placed in NASA

NASA be required to prepare at an early date a methodology for establishing a structure of user tariffs.

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